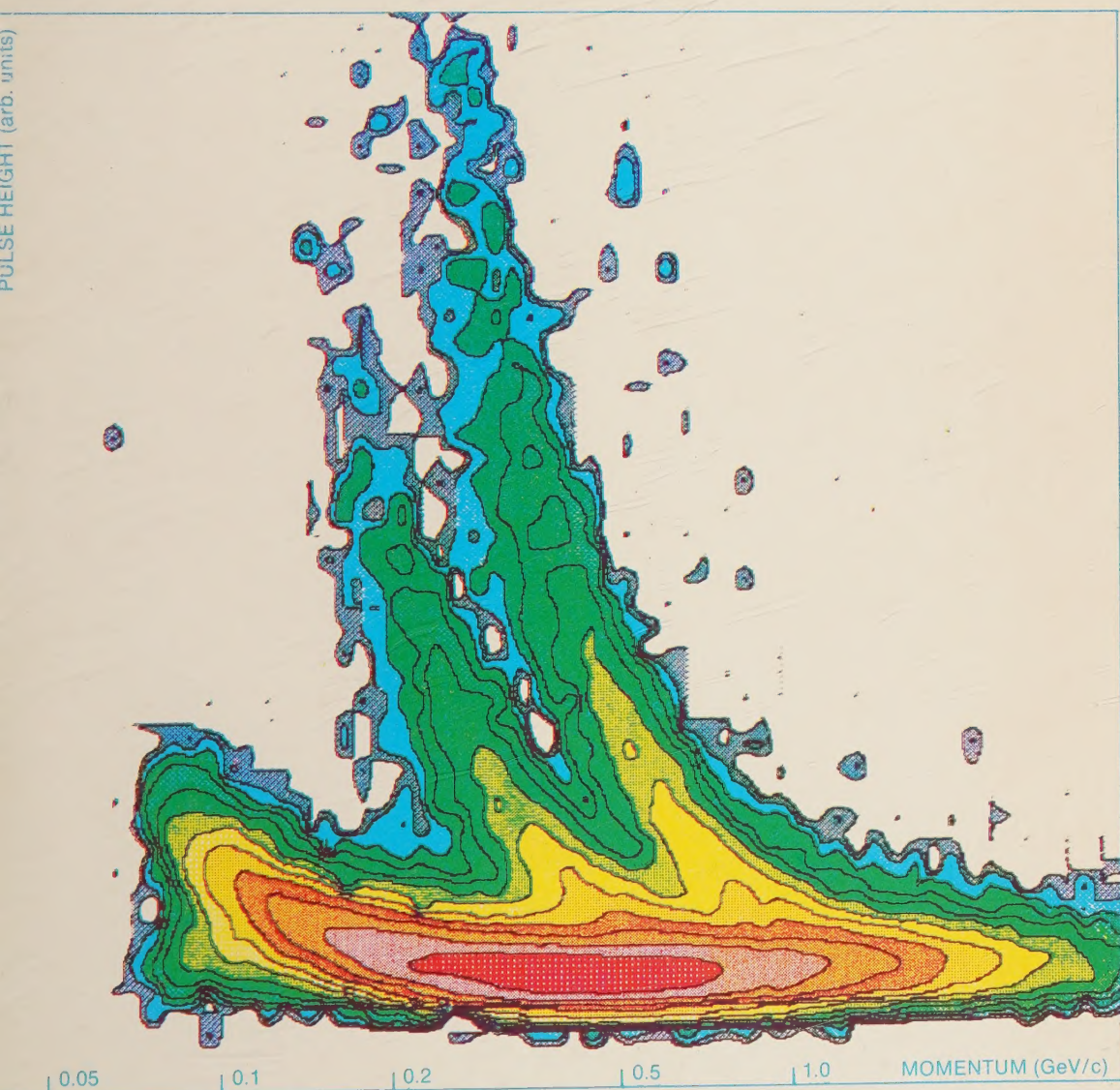
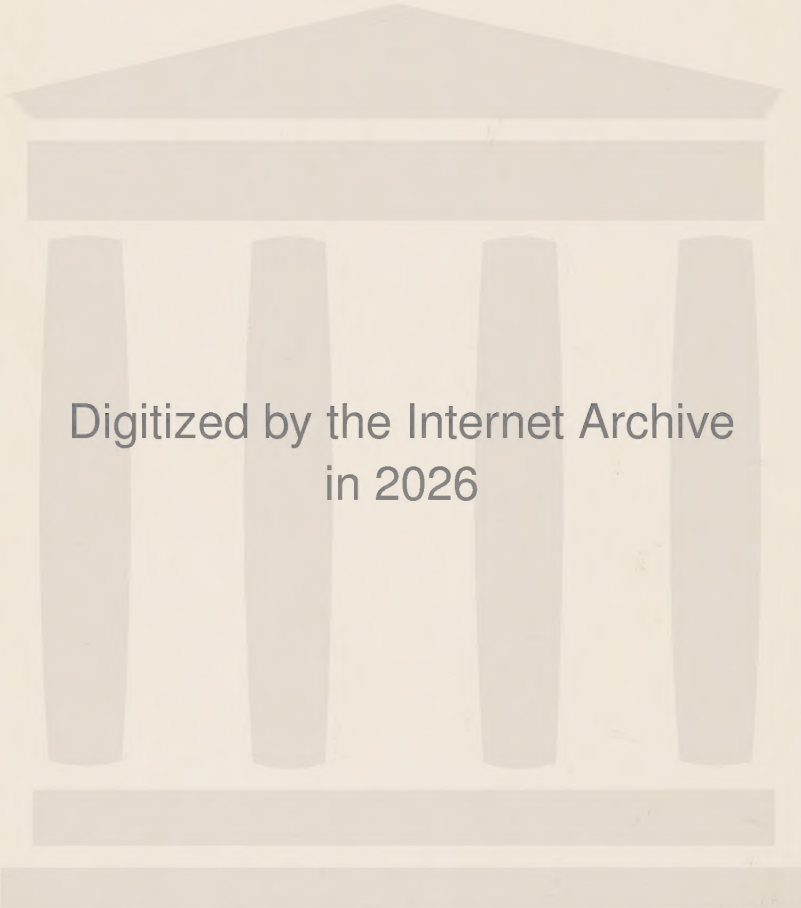


VECTOR MESON PRODUCTION IN PROTON-PROTON COLLISIONS AT VERY HIGH ENERGIES

Anders Melin



Lund 1982



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BY

ANDERS MELIN

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Abstract This thesis concerns measurements of inclusive production of ρ^0, $K^*(890)$ and ϕ as a function of transverse momentum, rapidity and incident energy. The studies were carried out using two electronic spectrometers, the Split-Field Magnet and the Axial Field Spectrometer, at the CERN intersecting storage rings, at C.M. energies ranging from 22 to 63 GeV. The cross-sections were found to be sizeable and in agreement with simple statistical quark models.		
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LUND 1981

PLATE 12

THE GARDEN OF THE MONASTERY OF SAINT PETER

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INTRODUCTION

Two particle correlations in high energy hadronic reactions have been extensively studied during the past decade. These studies have deepened our understanding of multiparticle production processes, but much remain to be done. In most of the early presented results (ref. 1), the correlations were described as a function of rapidity and azimuth, quantities which are rather insensitive to momentum as well as to particle type. The basic outcome of such studies was the clustering of particles, the so-called short range order.

Due to more sophisticated detectors, more momentum dependent variables can be used nowadays. In the low transverse momentum region this has meant that the interest has changed towards studies of structures such as resonance production and Bose-Einstein correlations. These studies were earlier concentrated to bubble chamber experiments, which operate at lower energies and, in most cases, give limited statistics and restricted particle identification. Nevertheless, it has become clear from such experiments that resonance production is sizeable and contribute substantially to short range order correlations.

The impact of new theoretical developments, in particular in the framework of quark-parton models, have focused the main interest to large transverse momentum processes, but have also affected studies of correlations in the low transverse momentum region. Simple statistical ideas (ref. 2) predict successfully different particle ratios, specifically the ratio of vector to pseudoscalar mesons. Attempts have also been made to predict differential cross-sections employing more detailed models which use information on the structure of hadrons obtained from deep inelastic lepton scattering. All these models demonstrate that production of heavier, resonant particles such as ρ^0 , might have large production cross-sections and will thus affect the inclusive cross-sections of the stable particles. This complicates the interpretation of π , K and proton spectra. The data on inclusive resonance production provide hence more direct information of multiparticle production processes.

The question of vector meson production cross-sections is the underlying theme of this thesis. The studies are carried out using data from two

different experiments performed at the CERN intersecting Storage Rings (ISR).

Although the physics results published from these experiments are many, this thesis is based only on publications concerning resonance production in the low transverse momentum region.

This dissertation is based on the following publications :

1. EVIDENCE FOR DOMINANT VECTOR-MESON PRODUCTION IN INELASTIC PROTON-PROTON COLLISIONS AT 53 GeV C.M. ENERGY.

G.Jansco, M.G.Albrow, S.Almehed, P.S.L.Booth, X.deBouard, J.Burger, H.Bøggild, L.J.Carroll, P.Catz, E.Dahl-Jensen, I.Dahl-Jensen, G.Damgaard, G.vonDardel, N.Elverhaug, B.Guillerminet, K.Hansen, P.Herbsleb, J.N.Jackson, G.Jarlskog, H.B.Jensen, L.Jönsson, A.Klovning, E.Lillethun, R.Little, E.Lohse, A.Lu, B.Lörstad, N.A.McCubbin, A.Melin, H.E.Miettinen, J.V.Morris, R.Møller, S.Ø.Nielsen, B.S.Nielsen, J.O.Pedersen, T.Sanford, J.A.J.Skard, D.B.Smith and P.Villeneuve.

Nuclear Physics B124 (1977) 1

2. INCLUSIVE ρ^0 -PRODUCTION IN pp COLLISIONS AT THE CERN ISR.

M.G.Albrow, S.Almehed, P.S.L.Booth, X.deBouard, H.Bøggild, L.J.Carroll, P.Catz, E.Dahl-Jensen, I.Dahl-Jensen, G.Damgaard, G.vonDardel, N.Elverhaug, K.H.Hansen, J.N.Jackson, G.Jansco, G.Jarlskog, H.B.Jensen, L.Jönsson, A.Klovning, E.Lillethun, A.Lu, B.Lörstad, N.A.McCubbin, A.Melin, H.E.Miettinen, R.Møller, B.S.Nielsen, S.Ø.Nielsen, J.O.Pedersen, J.A.J.Skard and P.Villeneuve.

Nuclear Physics B155 (1979) 39

3. INCLUSIVE VECTOR-MESON PRODUCTION IN THE CENTRAL REGION
OF pp COLLISIONS AT $\sqrt{s} = 63$ GeV.

T.Åkesson, M.G.Albrow, S.Almehed, O.Benary, H.Bøggild, O.Botner,
H.Brody, V.Burkert, A.diCiaccio, D.Cockerill, S.Dagan, E.Dahl-Jensen,
I.Dahl-Jensen, P.Dam, G.Damgaard, W.M.Evans, C.W.Fabjan, T.Ferbel,
P.Frandsen, S.Frankel, W.Frati, M.D.Gibson, H.Gordon, A.Hallgren,
K.H.Hansen, B.Heck, S.Henning, J.W.Hiddleston, H.J.Hilke, R.Hogue,
J.E.Hooper, G.Jarlskog, P.Jeffreys, G.Kessler, T.Killian, J.v.d.Lans,
P.R.Lindblom, J.Lindsay, D.Lissauer, E.Lohse, B.Lörstad, H.J.Lubatti,
T.Ludlam, N.A.McCubbin, A.Melin, U.Mjörnmark, R.Møller, W.Molzon,
B.S.Nielsen, S.Ø.Nielsen, A.Nilsson, L.H.Olsen, Y.Oren, L.Rosselet,
E.Rosso, A.Rudge, R.H.Schindler, B.Schistad, D.W.Wang, Ch.J.Wang,
W.J.Willis, M.Winik, W.Witzeling and C.Woody.

Preprint CERN-EP/82-01

(to be published in Nuclear Physics)

THE CERN INTERSECTING STORAGE RINGS

The CERN Intersecting Storage Rings (ISR) are capable of storing two beams of protons (and lately also antiprotons, deuterons and alpha particles) and bring them to collide at eight intersection points with a luminosity of about $5 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}$ (for protons). The storage rings are fed from the CERN 26 GeV/c proton synchrotron and operates at 22, 31, 44, 53 and 63 GeV C.M. energy. After stacking the beams, a procedure which is normally done in a couple of hours, ISR can run for several days without deteriorating the beams. Due to the high luminosity, the data which is discussed in this thesis, could be collected in a very short time (order of hours).

THE EXPERIMENTAL SET-UPS

The first two publications in this thesis use data from the Split-Field Magnet detector (SFM), which consists of multiwire proportional chambers (MWPC) placed in the magnetic field of the split-field magnet itself (figure 1). The magnet has yokes above and below one of the ISR

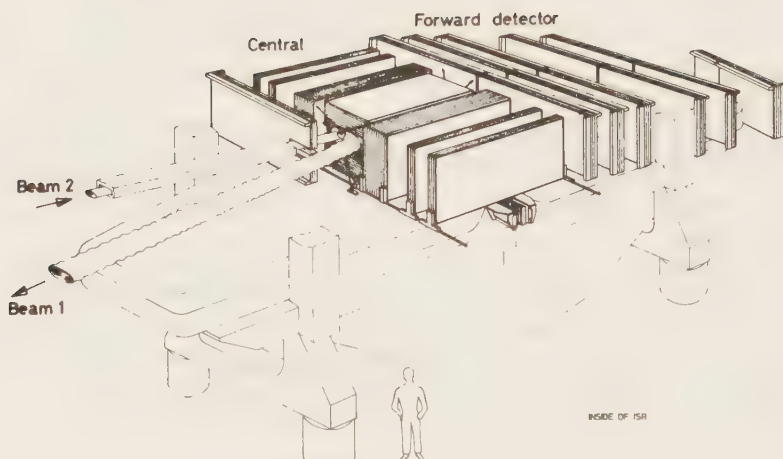


Figure 1. The Split-Field Magnet detector

interaction points, and they are separated by a 1.1 m gap. Its coils are oriented such that one side downstream of the interaction region has a magnetic field (order 1 T) pointing upwards and the other direction has a downwards directed field. This leaves a relatively weak field in the central region, and hence the SFM is mainly a forward spectrometer. The multiwire proportional chambers for particle detection are inserted in the gap between the yokes. These are grouped in three separated telescopes, two along the outgoing beams and one around the central region. The data was taken operating the detector in a self triggering mode, where at least two track candidates were required in any part of the detector. With this trigger $\sim 95\%$ of the total inelastic cross-section was accepted.

The third publication employs the Axial Field Spectrometer (AFS) (figure 2), a device which was constructed mainly for studying large transverse momentum processes in the central region. It consists of a magnet which generates an axially symmetric field (order 0.5 T),

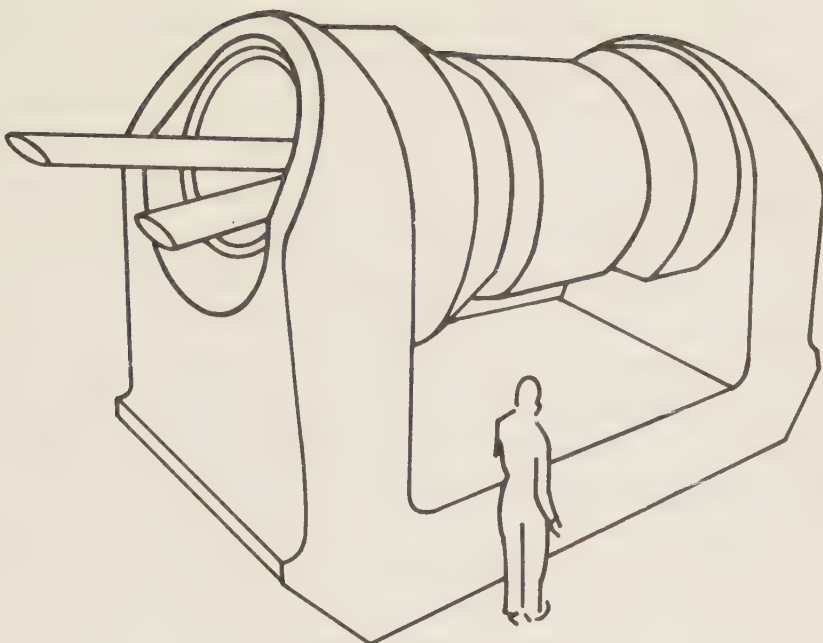


Figure 2. The Axial Field Spectrometer

in which a cylindrical drift chamber records the particle trajectories. The open gap between the polefaces has a length of 1.5 meters, which limits the track sensitive area to within ± 50 degrees. The particle ionization, which is also read out from the drift wires enables particle separation by dE/dx .

Both detectors are described in detail elsewhere (ref. 3,4).

The two spectrometers are thus somewhat complementary for studying low transverse momentum resonance production. The AFS operates in the central region where the SFM has its worst performance due to the low field and the rapidly changing acceptance. The ionization measurement also gives the possibility to study strange particle and baryon production in the AFS.

DATA REDUCTION AND ANALYSIS

A. The Split-Field Magnet

The off-line reconstruction software consist of a track finding

program (MARC) and a track and vertex fitting program (NICOLE). MARC groupes digitizings into clusters, and clusters into track candidates, which are sent to NICOLE together with their charge and momentum vector. Track candidates are first searched for separately in the forward and central telescopes, and then a merging of tracks from the different telescopes is attempted. Track candidates are found by forming a preliminary track candidate of three initial space points, and checking if this candidate meets a set of tests (eg. predicting hits in other chambers, track candidate points to interaction region). The geometry program NICOLE fits each track separately, using the magnetic field and the quintic spline method (ref. 5). From the tracks remaining after this procedure, a compatible subset is chosen for fitting to a common vertex.

All charged particles were taken as being pions except positive tracks with a Feynman $x > 0.4$ which has a probability of 80 % or more of being protons. The average relative momentum error is 11 % in the horizontal plane and 35 % in the vertical plane of the central telescope and 5 % in the forward telescopes. To improve the mass resolution, only tracks with $\Delta p/p < 0.3$ and $p_{cm} > 300$ MeV/c were used.

Al. Paper I

The total number of reconstructed events was $\sim 25\,000$ taken at a C.M. energy of 53 GeV.

Mass distributions of $\pi^+\pi^-$ and $\pi^\pm\pi^\pm$ was formed. The combinatorial background for both mass spectra was subtracted using randomly selected tracks taken from different events and normalizing to the same number of pairs in the high mass region where the correlation is expected to be small. The subtracted spectra show that while doubly charged combination have only a small correlation, the neutrals display a shoulder at the ρ^0 mass, together with a smooth distribution peaked at 0.47 GeV/c². An attempt to interprete the $\pi^+\pi^-$ spectra as being exclusively ρ mesons and $\pi^+\pi^-$ reflections from ω production was shown to be inadequate. Since this fit has "holes" in exactly the regions where other particles (ie. η , $K^*(890)$) have their reflections, a fit to the five resonances ρ^0 , ω , $K^*(890)$, η and f was tried, which gave a fair representation of the correlation.

Detector acceptances was estimated by Monte-Carlo means.

The conclusion from this paper is that, given the method, almost all of the stable mesons are decay products from vector mesons.

A2. Paper II

In this paper, data was studied from five different C.M. energies, $\sqrt{s} = 22, 31, 45, 53$ and 63 GeV. The number of reconstructed events was between 20 000 and 30 000 at each energy.

All possible $\pi^+\pi^-$ combinations were formed and the combinatorial background was determined as in section A1 above. The subtracted signal was fitted to a P-wave Breit-Wigner distribution plus a background function of the form $A/m + B/m^2$ in the mass range $0.5 - 1.5$ GeV/c². Other parametrizations of the background was also tried, indicating a systematic error contribution of ~ 25 %. The fit was done independently at the five energies, giving an energy dependence:

$$\sigma_{\text{incl}} = A \cdot \ln(s) + B$$

where $A = 0.38 \pm 0.02$ mb and $B = -2.1 \pm 0.4$ mb. The ρ^0/π^- ratio seems to be approximately independent of energy.

For each energy, the data was subdivided in transverse momentum and rapidity intervals. At all energies the p_T distribution out to 1.5 GeV/c is well represented by the form

$$d\sigma/dp_T^2 = A \cdot \exp(-B \cdot p_T^2)$$

with $B = 3.3 \pm 0.2$ (GeV/c)⁻². The rapidity dependence is consistent with scaling in the ISR energy frame.

B. The axial Field Spectrometer

As in the case of the SFM, the AFS off-line software consist of a track reconstruction program (INGER) and a geometry program (MARTHA). INGER finds track candidates basically by searching for straight rows of hits in a plane defined by radius and azimuthal angle. This is achieved by repeatedly shifting the phi-measurements and histogramming down to the phi axis. The track candidates are first independently fitted and then a common vertex is searched for in the geometry program MARTHA, using a procedure similar to the corresponding SFM program NICOLE.

From the initial sample $\sim 90\,000$ events were fully reconstructed. To reduce the background contamination, all tracks were required to originate from the event vertex and contain 10 or more space points. Furthermore, the χ^2/NDF given by the single track fit was required to be less than three. A final selection was applied on the measurement errors on the individual track parameters.

Kaons were identified from the ionization measurement, which was defined as the lower 70 % of the individual pulse heights. The front cover shows the truncated mean pulseheight versus momentum for positive particles.

Invariant mass distributions of $\pi^+\pi^-$, $K^+\pi^-$ and K^+K^- were formed, and the combinatorial backgrounds were subtracted in the same way as in paper I and II for $\pi\pi$ and $K\pi$ combinations. Clear peaks were seen ρ^0 , $K^*(890)$ and ϕ in the respective distributions. These were fitted with a P-wave Breit-Wigner with nominal masses and widths, together with an exponential non resonant background function in the ρ^0 case, and a linear for the other two.

For all resonances, the data was subdivided in transverse mass and rapidity intervals. The transverse mass inclusive distributions are well described by a simple exponential with a slope of $6.4 \pm 0.2 \text{ (GeV/c}^2\text{)}^{-1}$ for all resonances studied. The data can also be fitted to similar exponentials in p_T and p_T^2 .

Various particle ratios were formed, all showing consistency with the simple quark model (ref. 2).

The single particle acceptance was reconstructed by comparing the inclusive spectra to earlier published results. To translate single particle acceptances into vector meson acceptances, a Monte-Carlo technique was used.

COMPARISON BETWEEN THE DIFFERENT TYPES OF ANALYSIS

The problems of determining cross-sections are related to both statistics and to the parametrisation of the background. In particular, at high energies the parametrisation is a severe obstacle due to the small signal to background ratio arising from the large combinatorial background. In the literature one finds several different approaches, such as:

- a) Fitting the resonance directly to the obtained mass distribution together with some smooth background (polynomial, exponential).
- b) Attempt to remove the combinatorial background by taking uncorrelated tracks (from different events, inclusive spectra) and then fit the remaining correlation function with various distributions.
- c) use a background obtained from exotic mass combinations (eg. $\pi^-\pi^-$ for ρ^0 estimations).

The publications in this thesis use two quite different approaches. The first tries, after subtracting the combinatorial background, to fit the correlated signal with 2-body resonances and 2-particle reflections from 3-body decays. The other two follow more conventional methods by allowing for a smooth non-resonant background together with the resonance. Common for all three publications is the attempt to remove uncorrelated combinations from the mass spectra by the method of subtracting combinations of particles taken from different events.

Though the fitted distribution in paper I seems to approximately describe the data, this method contains some severe drawbacks. The fit itself does not fully represent the correlation in the region $0.8 - 1.1$ GeV/c². Also, the high end tail of the fit relies entirely on the long tails of P-wave Breit-Wigner distributions. According to low energy investigations (ref. 6) these tails seem not to be justified. In addition, enters into this the question if the Breit-Wigner line shapes should be folded with effective phase space rather than the full phase space. Low energy bubble chamber results claim better fits using effective phase space. The conclusion is thus that though vector mesons contribute substantially to the two particle correlation at high energies they fail to describe it in total.

RESULTS

The conclusions from the publications discussed in this thesis are:

- a) Most, but not all, of the correlation function in pp-collisions is a reflection of vector meson production. It is however an open question if other resonances can account for the rest.

- b) $\sim 60\%$ of all pseudoscalar mesons are decay products of vector mesons in the central region. This is a value which is predicted from a simple quark model based on spin statistics arguments if higher spin resonances are taken into account.
- c) The ratio $\rho^0:K^*: \phi$ is approximately 9:3:1, ie. a suppression by a factor three for each strange quark contained in the particle.
- d) The ratio ρ^0/π^- is independent of energy at C.M. energies above 20 GeV.
- e) The inclusive transverse mass distributions can be described by an exponential with a slope 6.4 ± 0.2 , and are independent of energy and particle type.
- f) ρ mesons appear to scale at ISR energies.

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